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RESEARCH MEMORANDUM

EFFECT OF RETRACTABLE IGNITION PLUG ON PLUG FOULING BY CARBON DEPOSITS

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RESEARCH MEMORANDUM

EFFECT OF RETRACTABLE IGNITION PLUG ON PLUG FOULING BY CARBON DEPOSITS

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SUMMARY

An investigation was conducted using a single combustor from a 4600-pound-thrust turbojet engine to determine if ignition-plug fouling by carbon deposits could be prevented by retracting the plug from the combustion zone during operation after ignition had taken place. The fuels used were normally conducive to forming carbon. Investigations were also made to determine the effect a retractable ignition plug has on starting, altitude combustion efficiency, altitude operational limits, and temperature distribution at the combustor outlet and to compare these results with results obtained using a standard plug.

The retractable ignition plug (withdrawn from combustion zone) was not fouled with carbon deposits at engine conditions or with fuels that did cause the standard plug (in the combustion zone) to become fouled. Starting, altitude combustion efficiencies, and altitude operational limits determined with the standard plug were unaffected by the retractable plug. Temperature distribution at the combustor outlet obtained with the retractable plug was slightly improved over that obtained with the standard plug.

INTRODUCTION

The achievement of satisfactory ignition in turbojet engines, necessary at sea level and particularly vital at altitude (because of combustion blow-out or starting of extra engines for high power requirements), may become a serious problem with current engines and high-aromatic-content and low-volatility fuels. One cause of failure to start in current engines is ignition-plug fouling caused by carbon deposits. Data of reference 1 indicate that use of fuels with lower volatility or fuels with higher aromatic content increases carbon deposition. Investigations of fuels conforming to specification AN-F-58 in current turbojet engines, which were developed for a different fuel, indicate that with AN-F-58 fuels a possible

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deleterious effect of carbon deposition on engine performance is ignition-plug fouling (reference 2). Fouling occurred in 17 hours of running time at simulated engine conditions of 90-percent normal rated engine speed and 20,000-foot altitude.

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An investigation was made at the NACA Lewis laboratory to determine if ignition-plug fouling could be prevented by retracting the plug from the combustion zone after ignition. The fuels used varied in volatility and in aromatic content. Investigations were also conducted to determine if starting, altitude combustion efficiency, altitude operational limits, and temperature distribution at the combustor outlet would be affected by the change in air distribution in the combustion zone caused by the change in plug position.

The ignition-plug-fouling investigations were conducted at simulated engine conditions of 90-percent normal rated engine speed and 20,000-foot altitude with a modified AN-F-58 fuel and with a pure aromatic fuel. Starting data were obtained with two modified AN-F-58 fuels, and with AN-F-32 fuel at simulated sea-level operation over a range of ambient-air temperatures from 90° to -52° F. Altitude-combustion-efficiency and altitude-operational-limit data were determined at one engine speed, 70-percent normal rated, with one of the modified AN-F-58 fuels and with the pure aromatic fuel. Temperature distributions at the combustor outlet were determined at simulated engine conditions of 90-percent normal rated engine speed and 20,000- and 35,000-foot altitudes with a modified AN-F-58 and with a pure aromatic fuel.

APPARATUS

A description of the single combustor from a 4600-pound-thrust turbojet engine, the auxiliary equipment, the instrumentation, and the location of instrumentation is given in detail in reference 2.

The retractable ignition plug and assembly used to obtain data reported herein are shown in figure 1. The springs A keep the ignition plug D in the standard position for ignition. The plug may be moved along the guide rods B to the operating position by any suitable electrical, mechanical, hydraulic, or combination method. The bellows C act as a flexible seal allowing the plug to be moved back and forth. The ignition plug was a standard ignition plug from the engine used with the center electrode and shell lengthened approximately 1 inch to compensate for the length of the bellows. The standard dome was modified by the addition of a shield E that protects the ignition plug when retracted.

A diagrammatic cross section of the standard and the retractable ignition plugs located in the combustor is presented in figure 2. The standard plug and the approximate air-flow pattern through and around the plug are shown in figure 2(a). Figure 2(b) shows the air flow through the retractable ignition plug, which is in the same relative position as the standard plug; this position, hereinafter called the starting position, was used for the starting investigations and for the initial ignition of the combustor for the other tests. In the starting position the air flow from around the retractable plug is shutoff by the shield. Figure 2(c) shows the retractable ignition plug in a position hereinafter designated the operating position, and the air flow through and around the plug. In the operating position, the plug electrodes are inside the shield and are swept by the incoming air.

FUELS

Two of the four fuels used in this investigation were modified AN-F-58 fuels: one designated a high-aromatic AN-F-58, which has an aromatic content of 29 percent (maximum specification limit is 25 percent); and the other called a low-volatility AN-F-58, which had the Reid vapor pressure adjusted from a value of about 5 pounds to 1 pound per square inch. The other two fuels were a pure aromatic fuel known as aromatic solvent and a fuel specified as AN-F-32.

Analyses of the fuels are given in the following table:

	FUEL			
	High-aromatic AN-F-58	Low-volatility AN-F-58	Aromatic solvent	AN-F-32
A.S.T.M. distillation D86-46, °F				
Initial boiling point	110	200	310	336
10-percent evaporated	164	248	322	356
50-percent evaporated	370	356	324	375
Final boiling point	590	564	370	446
Aromatics, (percent by volume)				
Silica gel[a]	29	24	98	15
Specific gravity	0.806	0.801	0.874	0.831
Reid vapor pressure (lb/sq in.)	4.8	1.0		
Hydrogen-carbon ratio	0.150	0.155	0.115	0.154

[a]Determined by modified method of reference 3.

PROCEDURE AND RESULTS

Ignition-Plug Fouling

Investigations to determine the effect of plug position and dome modification (figs. 2(a) and 2(c)) on ignition-plug fouling were made with high-aromatic AN-F-58 and with aromatic solvent at simulated engine conditions of 90-percent normal rated engine speed, 20,000-foot altitude, and a Mach number of 0. The retractable ignition plug was in the starting position for ignition only and then withdrawn to the operating position (figs. 2(b) and 2(c), respectively). 1355

High-aromatic AN-F-58. - The standard plug was fouled (ignition impossible) after 6 hours of operating time as shown in figure 3(a), although the carbon deposits on the plug electrodes were considered light. After cleaning the plug, another 6-hour run was made and the plug was not fouled although the gap between the electrodes was about one-third of normal (fig. 3(b)). For the 12-hour running time with the high-aromatic AN-F-58, no large carbon deposits were formed either on the dome or the liner. The primary-air louvers were partly blocked, however, and the deposits on the nozzle might have been affecting the fuel spray.

The carbon deposits after a 12-hour run with high-aromatic AN-F-58 and the retractable ignition plug are shown in figure 4(a); the plug was not fouled. Figure 4(b) is the same as figure 4(a) except the plug has been moved to the starting position for better examination of the electrodes.

Aromatic solvent. - The standard plug was fouled after 6 hours of operation as shown in figure 5(a). With the aromatic solvent, the carbon deposits on the liner, the dome, and the primary-air louvers were much heavier than the deposits obtained with the high-aromatic AN-F-58 as would be predicted from the data of reference 1. After the plug was cleaned, another 6-hour run was made; the plug was again fouled and the deposits on the other parts of the combustor had increased (fig. 5(b)).

As shown in figure 6, the retractable plug was not fouled after either 6 or 16 hours of run time with the aromatic solvent. Figures 6(a) and 6(b) are the same except the plug has been moved to the starting position in figure 6(b) for better examination of the electrodes after a 6-hour run. Figures 6(c) and 6(d) show the carbon deposits in the combustor after an additional 10 hours of operation had been accumulated.

Starting

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Investigations of the effect of plug position and dome modifications on starting were determined with AN-F-32, low-volatility AN-F-58, and high-aromatic AN-F-58 at an engine speed of 1500 rpm and sea-level ambient pressures at a Mach number of 0. Ambient-air temperature was varied from 90° to -52° F. The fuel was at ambient room temperature. The investigations were conducted with the standard plug (fig. 2(a)) and with the retractable plug in the starting position (fig. 2(b)).

With each ambient-air temperature investigated, the combustor inlet-air conditions were adjusted to the values corresponding to the designated engine condition. If a particular fuel ignited and a combustor-outlet temperature sufficient for acceleration was obtained, the procedure was repeated with a lower ambient-air temperature until either the proper combustor-outlet temperature or a lower ambient-air temperature was unobtainable. No attempt was made to determine the minimum fuel-air ratio at which ignition would occur for any of the fuels. The rate of fuel addition up to the maximum fuel flow used (150 lb/hr) was approximately the same for all the fuels and conditions investigated.

Ignition and proper combustor-outlet temperature were obtained with either plug and with each of the three fuels investigated at ambient-air temperatures down to -52° F, which was the lowest temperature available. The data indicated that no noticeable difference in starting existed between the two ignition plugs over the limited range investigated and with the fuel-addition method used.

Data from unpublished studies conducted at the NACA Lewis laboratory show that with controlled fuel flow or fuel-air ratio during ignition there is a minimum value of fuel flow below which ignition will not occur. This value increases with decrease in ambient-air temperature and increases with increase in the 10-percent evaporated temperature of fuels.

With the standard plug (fig. 2(a)), certain engine conditions and fuels probably require an excessive amount of fuel for a proper fuel-air mixture around the ignition source. This requirement often results in "hot-starts", which are detrimental to the engine. Use of the retractable plug at these conditions may result in the proper fuel-air mixture for ignition at the plug at lower values of fuel flow because the incoming air from around the plug is blocked (fig. 2(b)).

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Altitude Combustion Efficiency and Altitude Operational Limits

The investigations to determine the effect of ignition-plug position and dome modification (figs. 2(a) and 2(c)) on altitude combustion efficiency and altitude operational limits were made with high-aromatic AN-F-58 and aromatic solvent at a simulated engine speed of 70-percent of normal rated and a Mach number of 0.

The altitude operational limit is defined as the altitude above which the combustor will not deliver sufficient temperature rise to operate the engine at a designated rotational speed. The data for the selection of the required temperature rise at each condition were obtained from the manufacturer's estimates.

For 70-percent normal rated engine speed and at each altitude condition, the fuel flow was increased after ignition in an effort to obtain an average combustor-outlet temperature equal to or greater than that required for engine operation at altitudes from 20,000 feet to the operational limit.

Data showing the altitude operational limits and variation of combustion efficiency with altitude are presented in figure 7. The altitude limits obtained with use of the standard and the retractable plugs (figs. 2(a) and 2(c), respectively) and with either fuel varied from 52,500 to 53,750 feet; in general, the retractable plug had no effect on the limits as determined with the standard plug. The combustion efficiencies at altitude were approximately the same for both standard and retractable plugs.

Temperature Distribution at Combustor Outlet

Investigations were made to determine if the use of the retractable ignition plug and dome modifications would affect the temperature distribution at the combustor outlet as determined with the standard plug. Two fuels, high-aromatic AN-F-58 and aromatic solvent, were used at simulated engine conditions of 90-percent normal rated engine speed, altitudes of 20,000 and 35,000 feet, and at a Mach number of 0. After ignition, the desired simulated engine conditions were established and the readings of 16 thermocouples (eight pairs) at the combustor outlet (reference 2, fig. 2, section C-C) were recorded when conditions had stabilized. The data were measured in the circular duct; the transition piece to convert the circular cross section to an annular segment was not used. Two more sets of data were recorded at 1/2-hour intervals. The data used for any one thermocouple station were the average of the six readings for that station (three for each thermocouple).

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The temperature distribution at the combustor outlet for simulated engine conditions at altitudes of 20,000 and 35,000 feet is shown in figure 8. The radial position of the plug is shown on the two figures. Because the results of the two fuels (high-aromatic AN-F-58 and aromatic solvent) had similar trends, only data of high-aromatic AN-F-58 are presented.

The average combustor-outlet temperature obtained with the retractable ignition plug and modified dome was more than 100° F less in an area opposite the plug position than the temperature obtained with the standard plug, for both altitude conditions. The temperature decreases of approximately 100° F, which may or may not be significant, were probably caused by a change in air distribution in the combustion zone when the retractable plug was used. In general, with the equipment used in these investigations, an improvement in the temperature distribution at the combustor outlet was obtained by use of the retractable plug and modified dome.

SUMMARY OF RESULTS

A retractable ignition plug designed to avoid fouling due to carbon deposits was compared with a standard ignition plug on the basis of plug fouling, starting, altitude combustion efficiency, altitude operational limits, and temperature distribution; the following results were obtained:

1. Retracting the ignition plug from the combustion zone after ignition prevented plug fouling by carbon. The retractable ignition plug investigated was not fouled with carbon deposits after 12 to 16 hours of operation by engine conditions or by fuels that caused fouling (ignition impossible) of the standard plug in 6 hours.

2. The retractable ignition plug had no deleterious effect on starting when compared with a standard plug over the range of conditions investigated.

3. The altitude operational limits and the altitude combustion efficiencies obtained with the retractable ignition plug were within experimental error of the limits and efficiencies obtained with the standard plug.

4. The temperature distribution at the combustor outlet obtained with the retractable ignition plug was slightly improved over that obtained with the standard plug.

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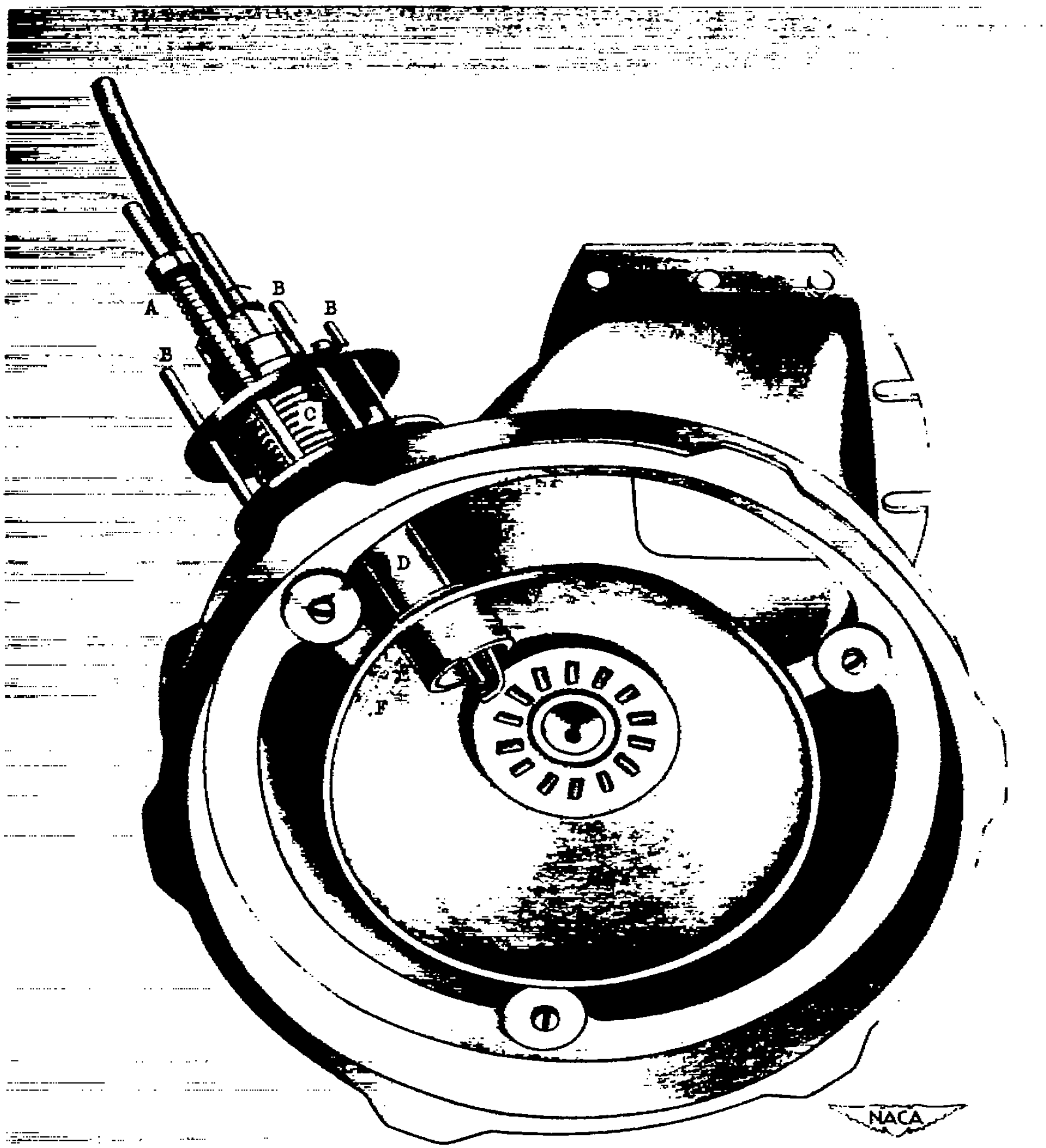
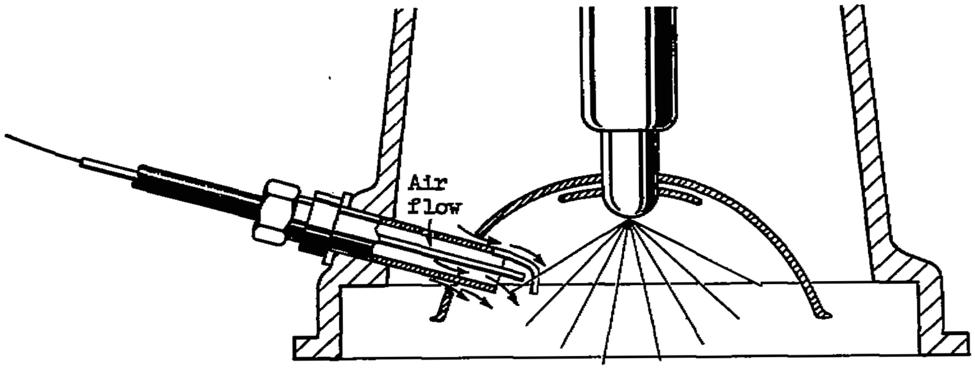
2. Wear, Jerrold D., and Douglass, Howard W.: Carbon Deposition from AN-F-58 Fuels in a J33 Single Combustor. NACA RM E9D06, 1949.

3. Gooding, Richard M., and Hopkins, Ralph L.: The Determination of Aromatics in Petroleum Distillates. Papers Presented before Div. Petroleum Chem., Am. Chem. Soc. (Chicago, Ill.), Sept. 9-13, 1946, pp. 131-141.

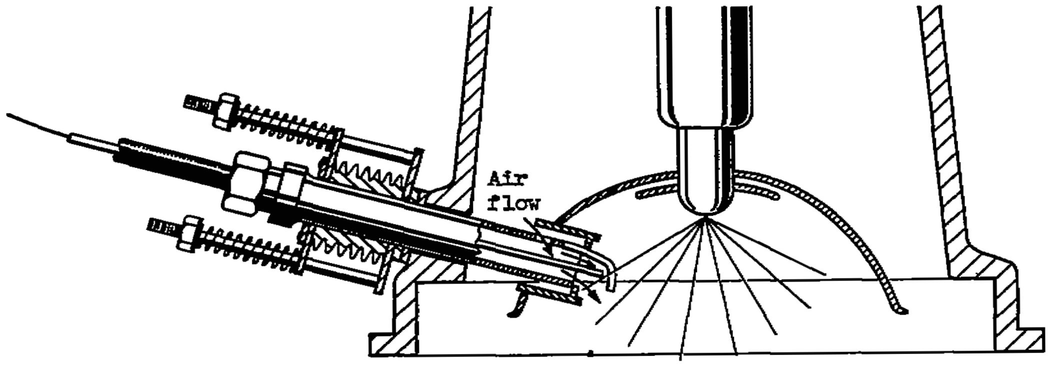


A Adjustable springs for holding plug in starting position
B Guide rods
C Bellows
D Retractable ignition plug
E Shield
F Dome

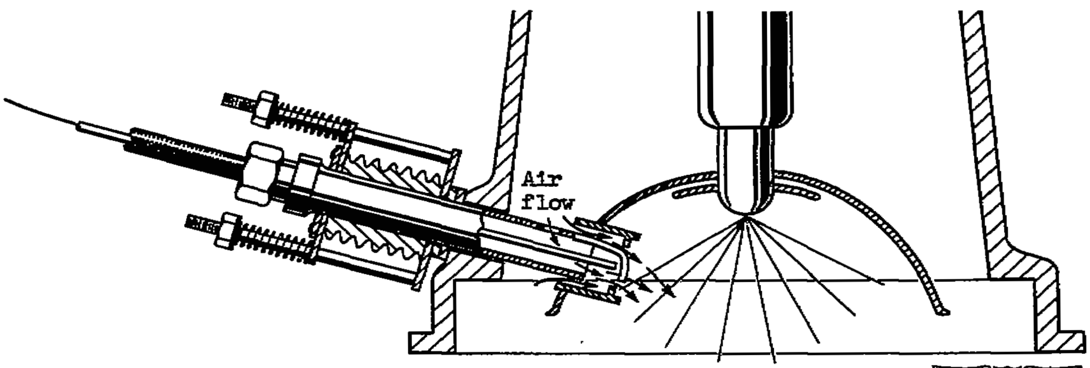
Figure 1. - Retractable ignition plug and assembly.



(a) Standard ignition plug.

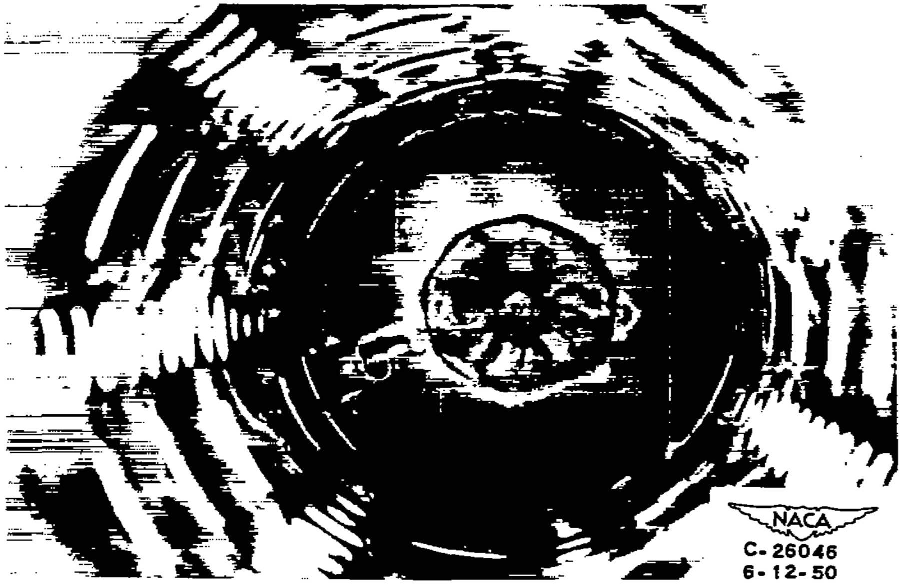


(b) Retractable ignition plug in standard or starting position.

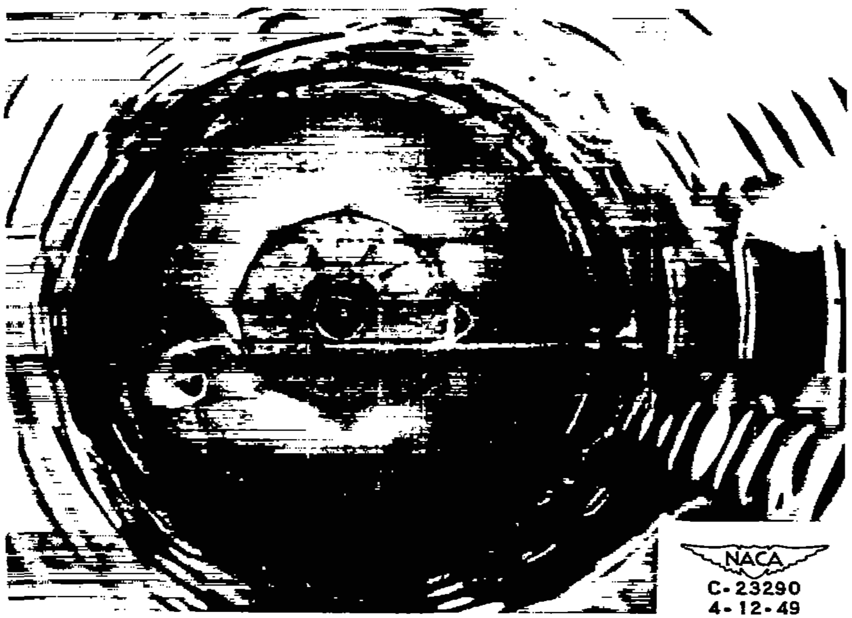


(c) Retractable ignition plug in withdrawn or operating position.

Figure 2. - Diagrammatic cross sections of standard and retractable ignition plugs installed in combustor.

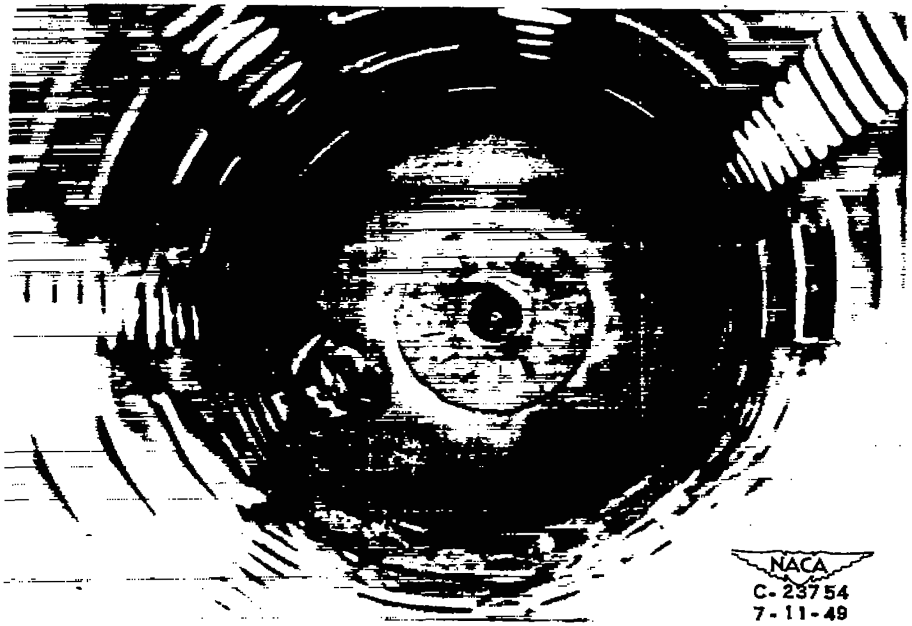


(a) Plug fouled by carbon deposits. Plug operating time, 6 hours; combustor operating time, 6 hours.

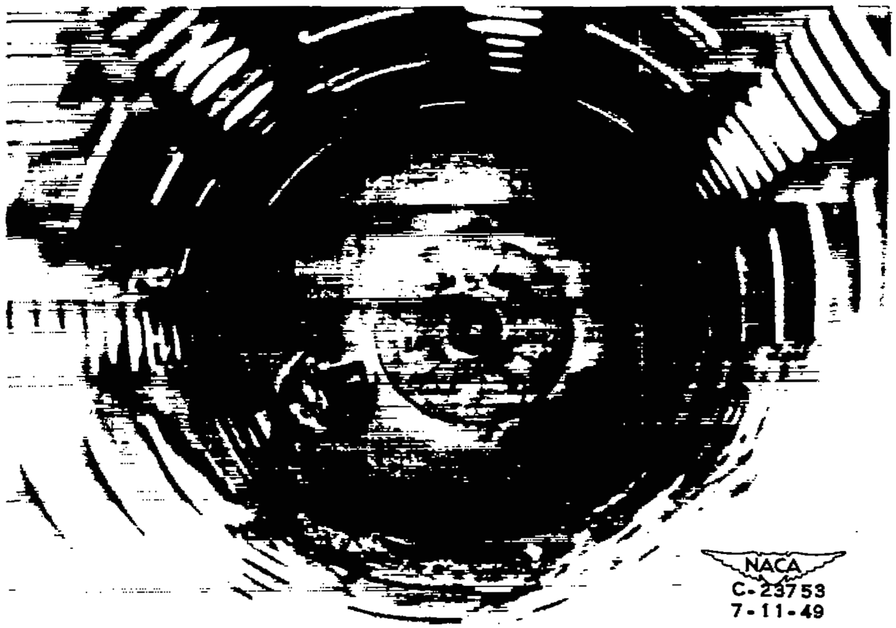


(b) Plug not fouled by carbon deposits. Plug operating time after cleaning, 6 hours; accumulated combustor operating time, 12 hours.

Figure 3. - Standard ignition plug. Fuel, high-aromatic AN-F-58; simulated engine conditions: engine speed, 90-percent normal rated; altitude, 20,000 feet; flight Mach number, 0.

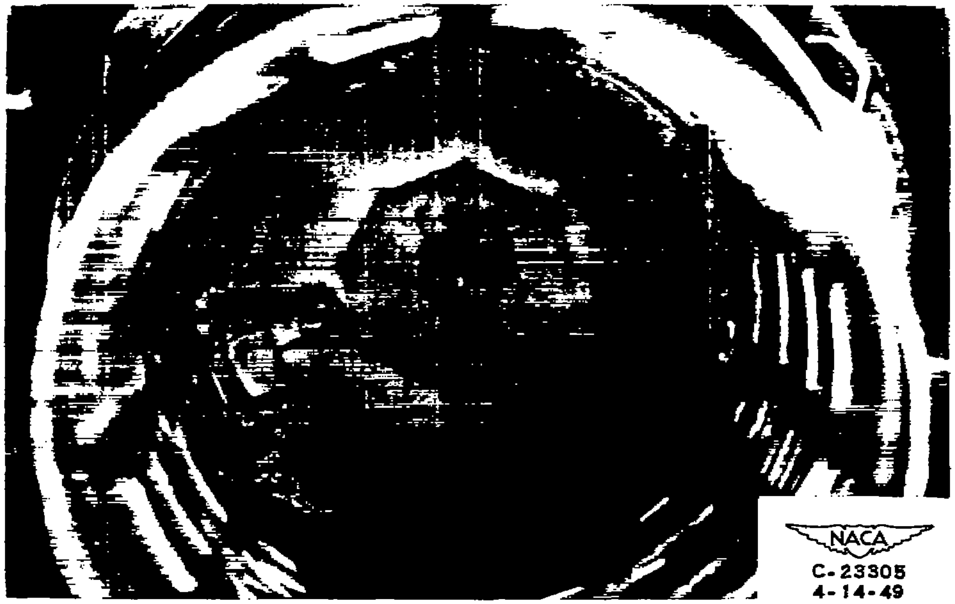


(a) Operating position.

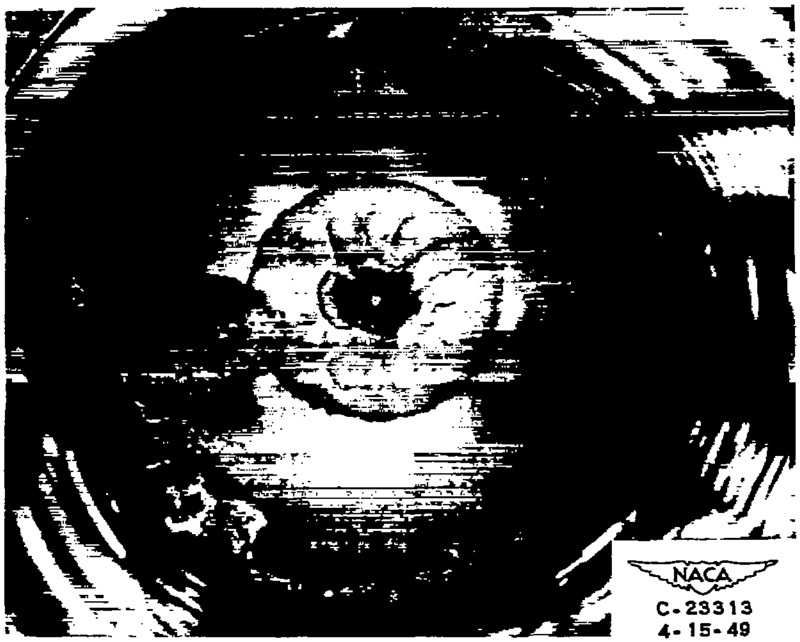


(b) Starting position.

Figure 4. - Retractable ignition plug not fouled by carbon deposits. Operating time, 12 hours. Fuel, high-aromatic AN-F-58; simulated engine conditions: engine speed, 90-percent normal rated; altitude, 20,000 feet; flight Mach number, 0.

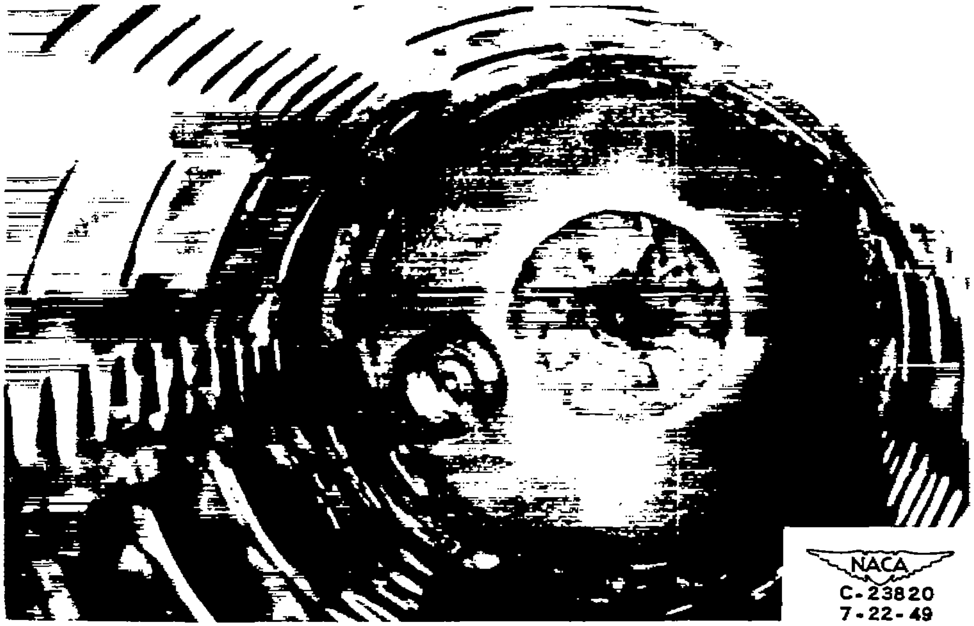


(a) Plug operating time, 6 hours; combustor operating time, 6 hours.

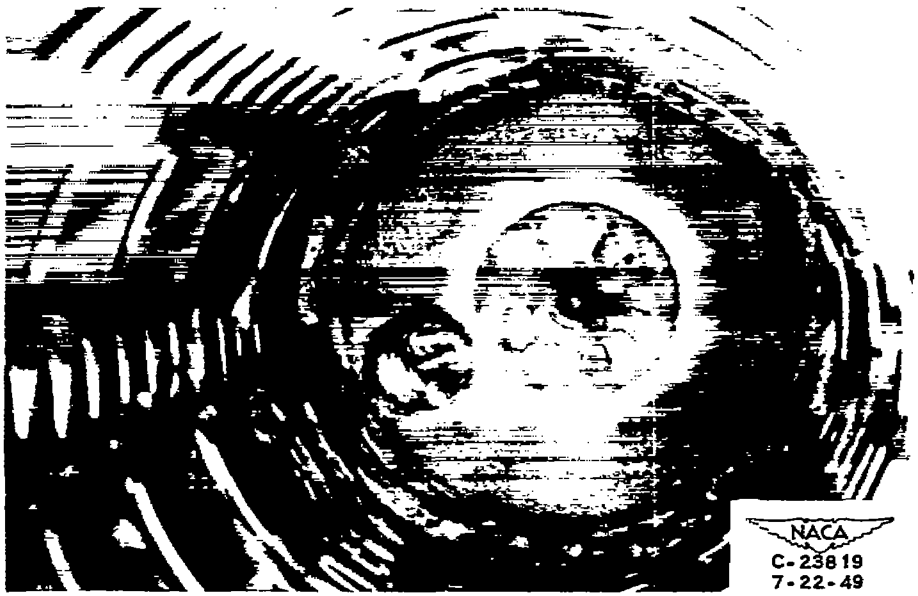


(b) Plug operating time after cleaning, 6 hours; accumulated combustor operating time, 12 hours.

Figure 5. - Standard ignition plug fouled by carbon deposits. Fuel, aromatic solvent; simulated engine conditions: engine speed, 90-percent normal rated; altitude, 20,000 feet; flight Mach number, 0.

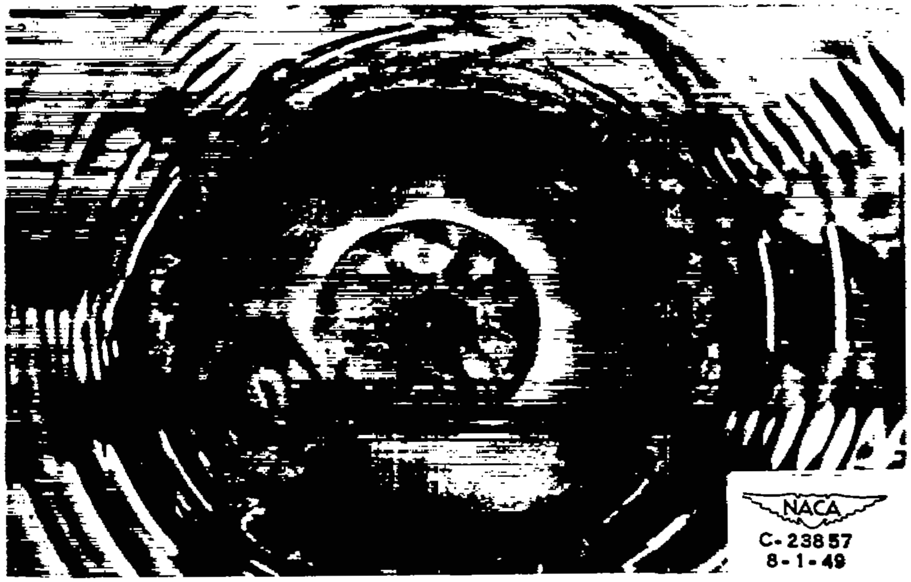


(a) Operating position. Operating time, 6 hours.

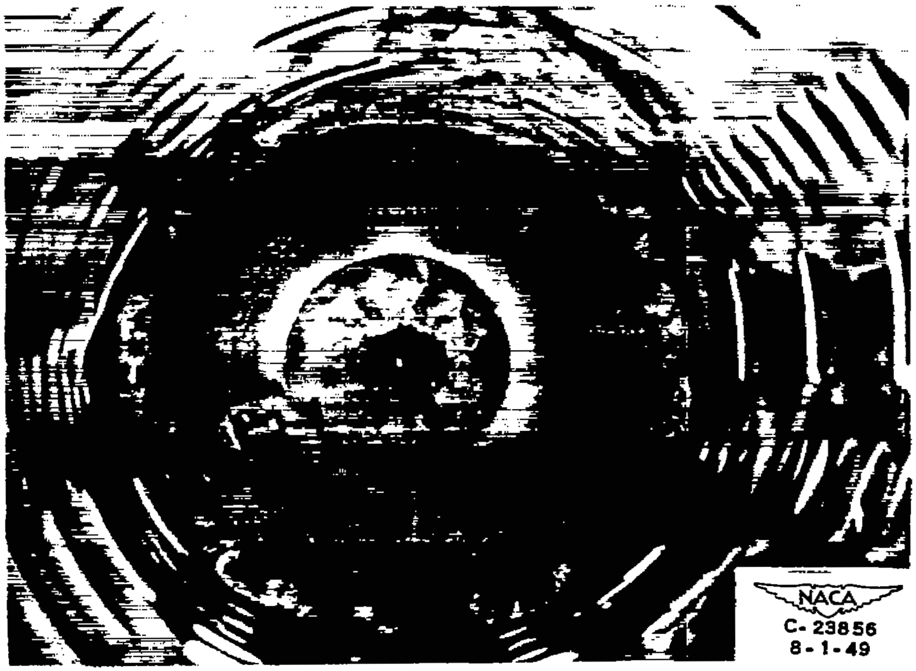


(b) Starting position. Operating time, 6 hours.

Figure 6. - Retractable ignition plug not fouled by carbon deposits. Fuel, aromatic solvent; simulated engine conditions: engine speed, 90-percent normal rated; altitude, 20,000 feet; flight Mach number, 0.

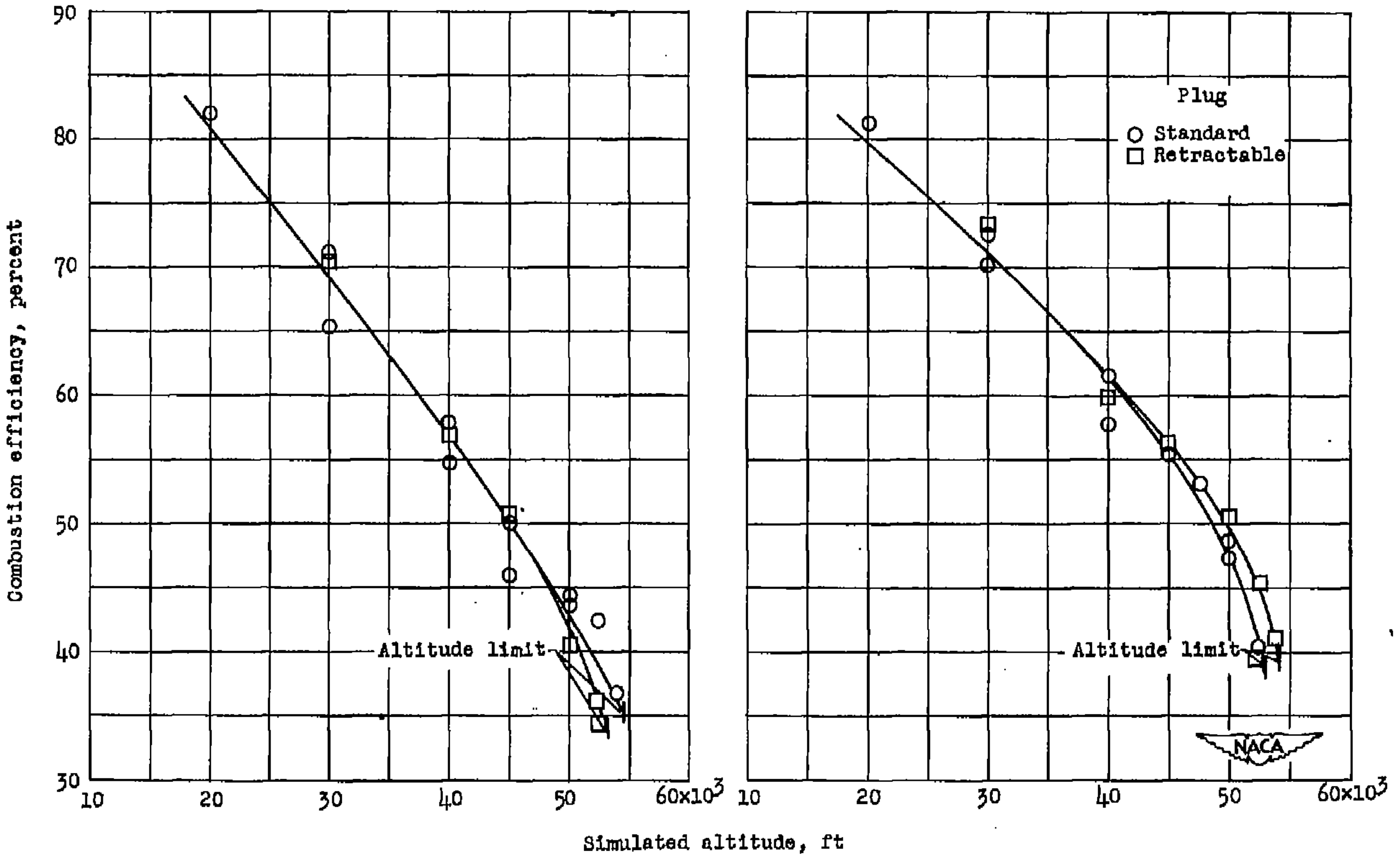


(c) Operating position. Operating time, 16 hours.



(d) Starting position. Operating time, 16 hours.

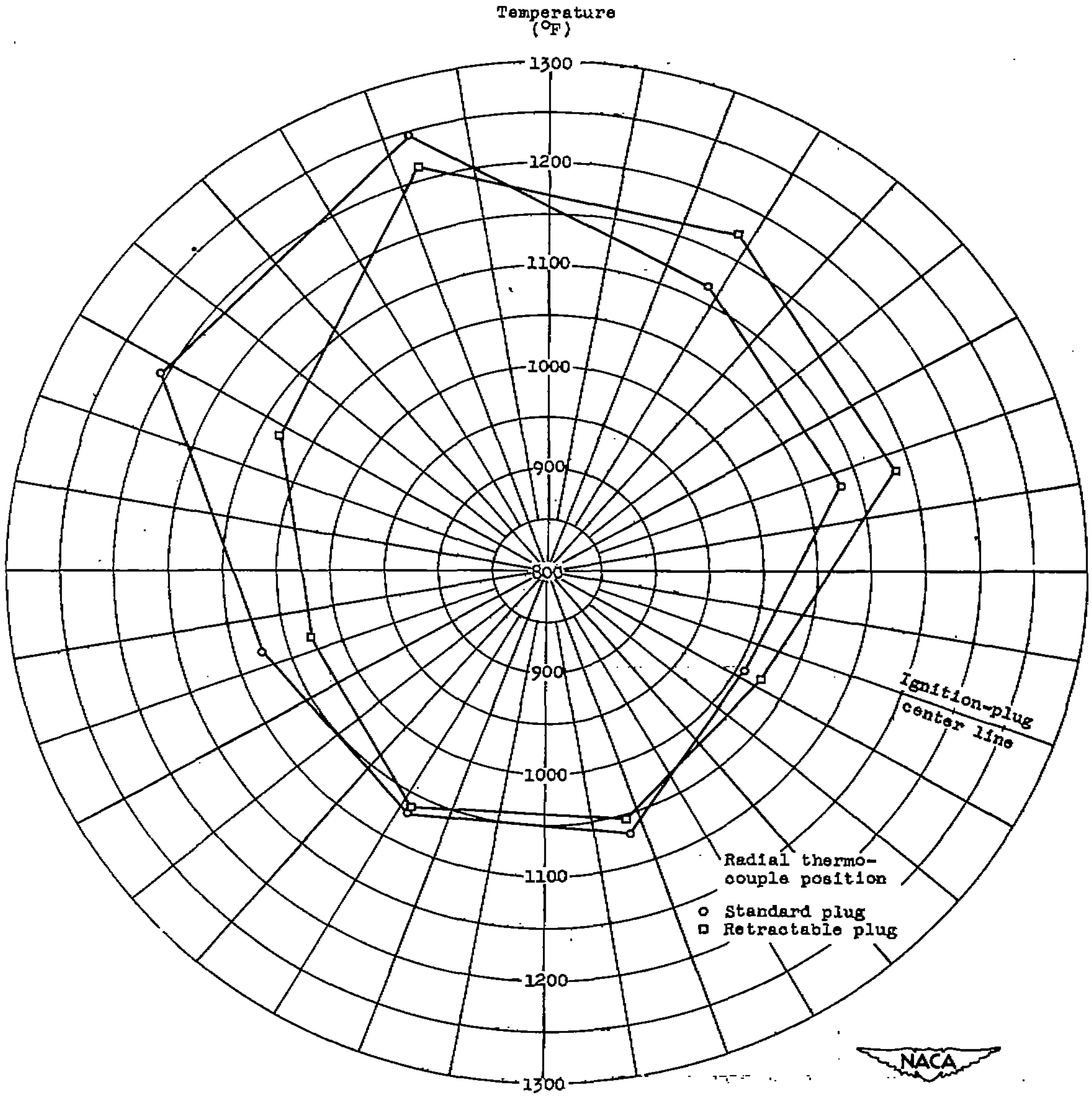
Figure 6. - Concluded. Retractable ignition plug not fouled by carbon deposits. Fuel, aromatic solvent; simulated engine conditions: engine speed, 90-percent normal rated; altitude, 20,000 feet; flight Mach number, 0.



(a) Aromatic solvent.

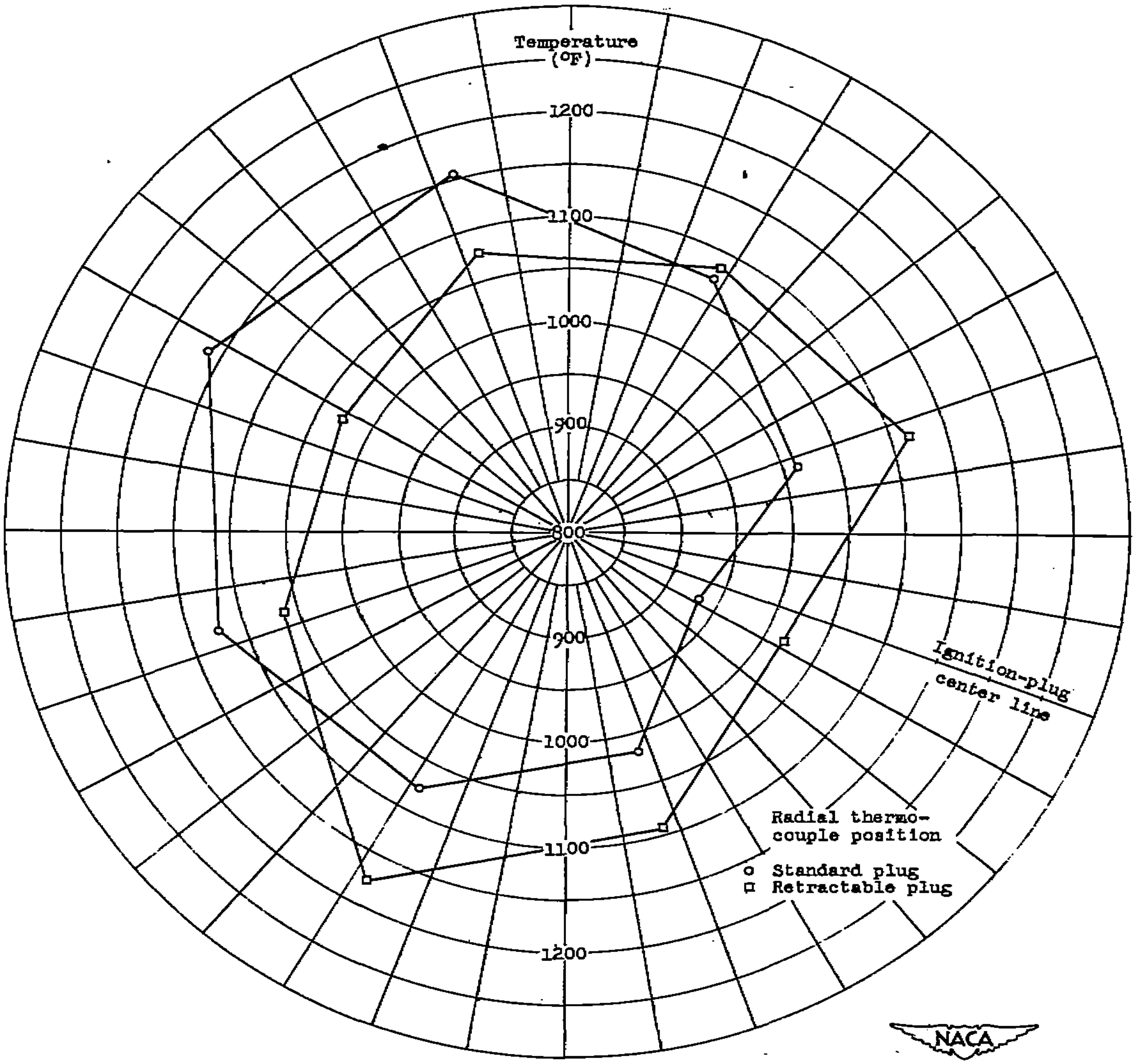
(b) High-aromatic AN-F-58.

Figure 7. - Altitude operational limits and variation of combustion efficiency with altitude determined with standard ignition plug and with retractable ignition plug. Simulated engine conditions: engine speed, 70-percent normal rated; flight Mach number, 0.



(a) Altitude, 20,000 feet.

Figure 8. - Combustor-outlet temperature distribution determined with standard ignition plug and with retractable ignition plug. Fuel, high-aromatic AN-F-58; simulated engine conditions: engine speed, 90-percent normal rated; flight Mach number, 0.



(b) Altitude, 35,000 feet.

Figure 8. - Concluded. Combustor-outlet temperature distribution determined with standard ignition plug and with retractable ignition plug. Fuel, high-aromatic AN-F-58; simulated engine conditions: engine speed, 90-percent normal rated; flight Mach number, 0.